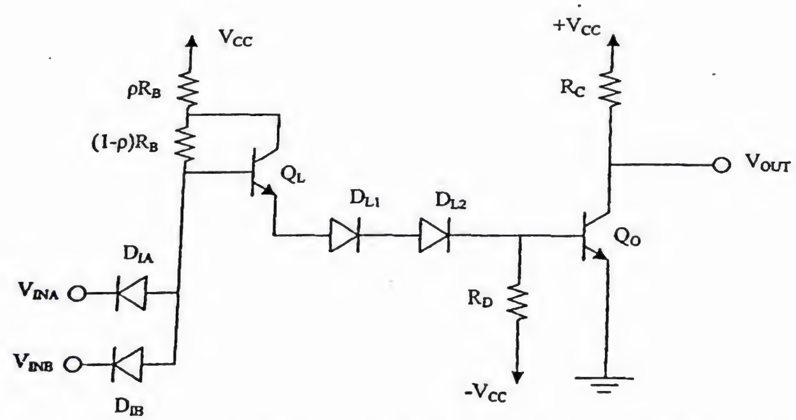
Question 3: [8 Marks]

Consider the following DTL NAND gate. Assume $V_{BE}(FA) = 0.7V$, $V_{BE}(SAT) = 0.8V$, $V_{CE}(SAT) = 0.2V$, $V_D(ON) = 0.7V$, $\beta_F = 50$, $R_D = 6K\Omega$, $R_B = R_C = 1K\Omega$, ρ= 0.3, $V_{CC} = 5V$. Find the following,

a) VTC (sketch)
b) The input low value of current I_{IL}.
c) The output low value of current I_{OL}.
d) The maximum fan-out
e) The average power dissipation



a) assume $V_{INA} = V_{INB} = V_{IN}$

Output high voltage $\equiv V_{OH}$

For Vin is low D_I is FB

Q_L, D_{L1}, D_{L2}, & Q_o is off

$V_{out} = V_{CC} = V_{OH} \Rightarrow \boxed{V_{OH} = 5V}$

Input low voltage $\equiv V_{IL}$

Increasing Vin until the point where Q_o just turns on when

$$V_{IN} = -V_D(ON) + V_{BE_L}(FA) + V_{DL1}(ON) + V_{DL2} + V_{BE_O}(FA) = V_{IL}$$

$$V_{IL} = 2V_{BE}(FA) + V_D(ON) = 2.1V$$

$$\boxed{V_{IL} = 2.1V}$$

Output low voltage $\equiv V_{OL}$

For V_{IN} is high D_I is off

Q_L, D_{L1}, D_{L2} & Q_o is on

increasing V_{in} further eventually drives Q_o into saturation

$$V_{out} = V_{CE,O}(sat) = V_{OL}$$

$$\boxed{V_{OL} = 0.2V}$$

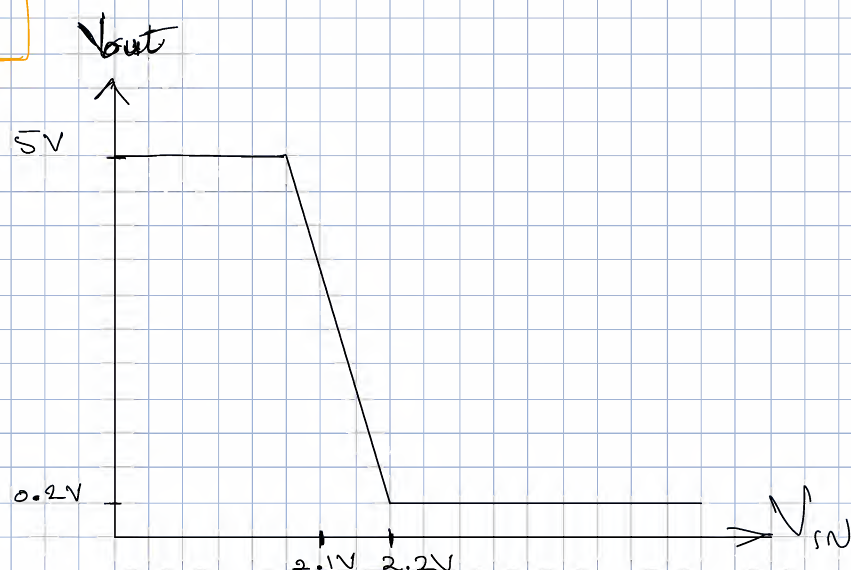
Input high voltage $\equiv V_{IH}$

Q_o enters saturation at

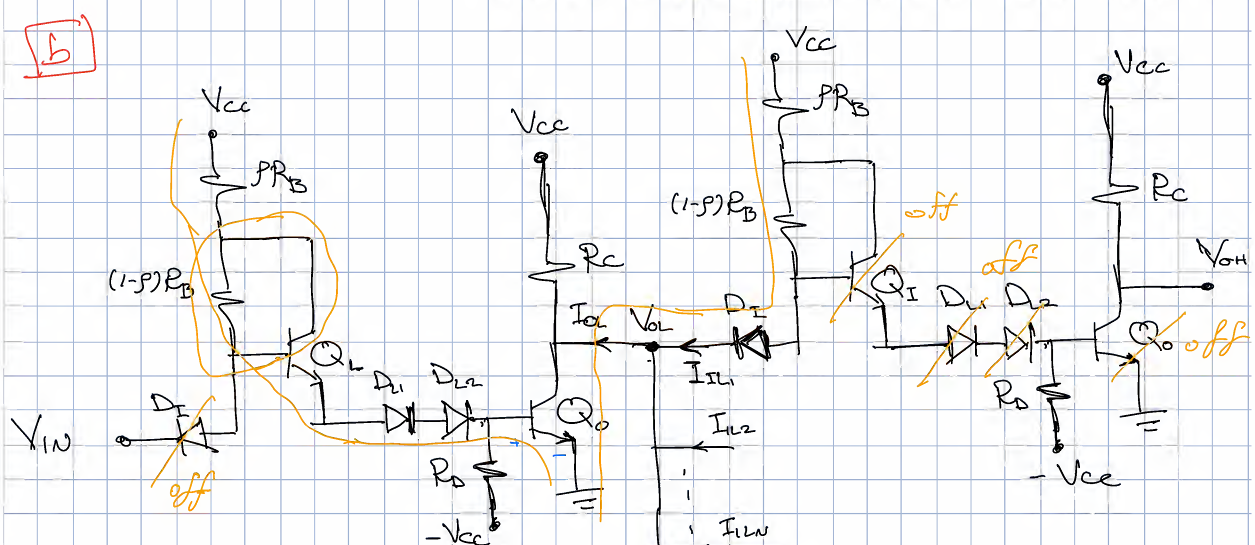
$$V_{IN} = -V_{DI}(ON) + V_{BE,L}(FA) + V_{DL1} + V_{DL2} + V_{BE,O}(sat) = V_{IH}$$

$$V_{IH} = V_{BE}(FA) + V_{BE}(sat) + V_{D}(ON) = 0.7 + 0.8 + 0.7 = 2.2V$$

$$\boxed{V_{IH} = 2.2V}$$



b



Input low current $\equiv I_{IL}$

$$I'_{IL} = I_{\rho R_B} = \frac{V_{CC} - V'_{DI(ON)} - V'_{CE,O(sat)}}{(1-\rho)R'_B + \rho R'_B}$$

$$I'_{IL} = \frac{V_{CC} - V'_{D,I(ON)} - V'_{CE,O(sat)}}{R'_B} = \frac{5-0.7-0.2}{1K} = 4.1\,mA$$

$$\boxed{I_{IL} = 4.1\,mA}$$

c) Output low current $\equiv I_{OL}$

$$I_{OL} = I_{C,O(sat)} - I_{RC}$$

$$I_{RC} = \frac{V_{CC} - V_{CE,O(sat)}}{R_C} = \frac{5-0.2}{1K} = 4.8\,mA$$

$$I_{C,O(sat)} = \sigma_{OL}\,\beta_F\,I_{B,O(sat)}$$

Assume $\sigma_{OL} = 1 \Rightarrow$ (EOC)

$$I_{B,O} = I_{E,L} - I_{RD} =$$

$$I_{RD} = \frac{V_{BE(sat)} + V_{CC}}{R_D} = \frac{0.8+5}{6K} = \frac{5.8}{6K} = 0.97\,mA$$

$$I_{E,L} = \frac{V_{CC} - V_{BE,L(FA)} - V_{DL1} - V_{DL2} - V_{BE,O(sat)}}{\rho R_B}$$

$$= \frac{V_{CC} - V_{BE(FA)} - 2V_{D(ON)} - V_{BE(sat)}}{\rho R_B} = \frac{5-0.7-2(0.7)-0.8}{(0.3)(1K)} = \frac{2.1}{0.3K}$$

$$\boxed{I_{E,L} = 7mA}$$

$$I_{B,O} = 7m - 0.97m = 6.03\,mA$$

$$I_{C,O} = 1 \times 50 \times 6.03m = 301.5\,mA$$

$$I_{O,L} = 301.5m - 4.8m$$

$$\boxed{I_{O,L} = 296.7\,mA}$$

d)

$$N = \frac{I_{OL}}{I_{IL}} = \frac{296.7m}{4.1m} = 72.37$$

$\Rightarrow$ The maximum fan-out = 72

$\boxed{e}$

$$P_{cc}(avg) = \frac{I_{cc}(OH) + I_{cc}(OL)}{2} V_{cc}$$

$$I_{cc}(OH) = I_{\rho R_B}(OH) + \cancel{I_{RC}(OH)}$$

$$= I_{\rho R_B}(OH) = I_{IL} = 4.1mA$$

$$I_{cc}(OH) = 4.1mA$$

$$I_{cc}(OL) = I_{\rho R_B}(OL) + I_{RC}(OL)$$

$$I_{\rho R_B}(OL) = I_{E,L} = \frac{V_{cc} - V_{BE,L}(FA) - V_{DL_1} - V_{DL_2} - V_{BE,O}(sat)}{\rho R_B}$$

$$= 7mA$$

$$I_{RC}(OL) = \frac{V_{cc} - V_{CE,O}(sat)}{R_C} = 4.8mA$$

$$I_{cc}(OL) = 7m + 4.8m = 11.8mA$$

$$P_{cc}(avg) = \frac{11.8m + 4.1m}{2}(5) = \frac{15.9 \times 5m}{2}$$

$$P_{cc}(avg) = 39.75mW$$

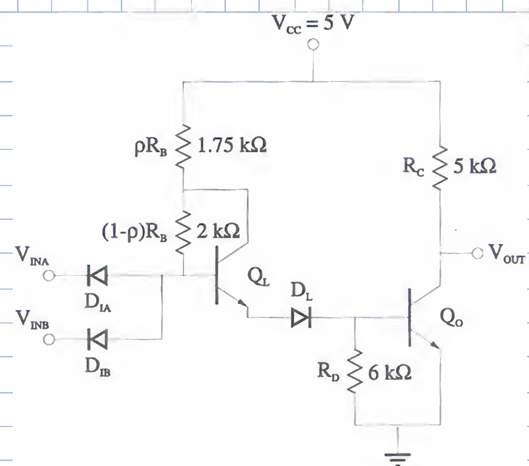
extra

$$V_{NMH} = V_{OH} - V_{IH} = 5 - 2.2 = 2.8V$$

$$V_{NML} = V_{IL} - V_{OL} = 2.1 - 0.2 = 1.9V$$

6.16

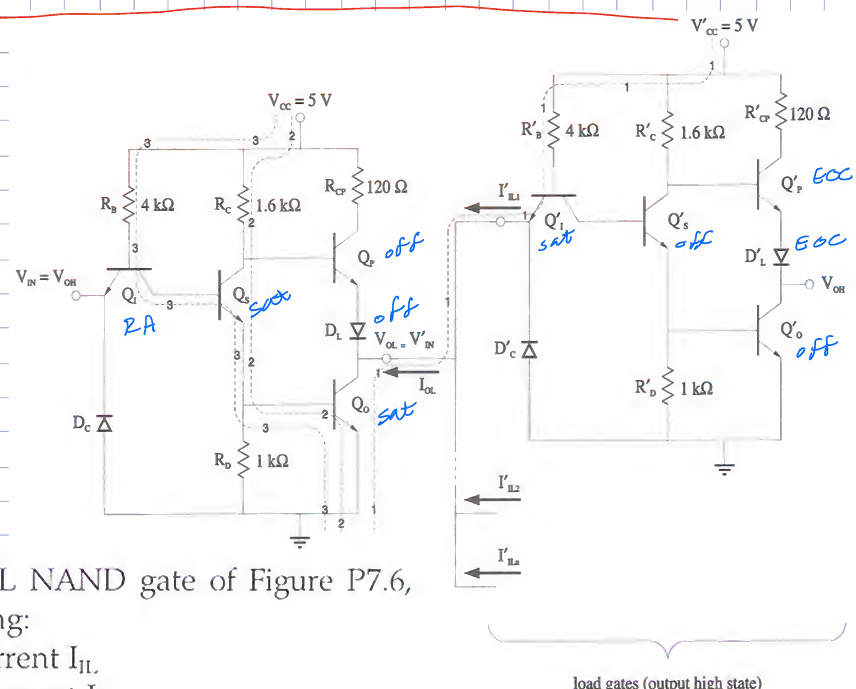
For the circuit of the right figure determine V_{OH} & V_{OL} for fan-out of $N = 10$



the fan-out N have no effect on V_{OH} & V_{OL} therefore

$$V_{OH} = V_{CC} = 5V$$

$$V_{OL} = V_{CE(sat)} = 0.2V$$



ge Power Dissipation Calculations

7.9 For the standard TTL NAND gate of Figure P7.6, calculate the following:

(a) the input low current I_{IL}

(b) the output low current I_{OL}

(c) the maximum fan-out $\equiv N = I_{OL}/I_{IL}$

(d) the average power dissipation

Use $\beta_F = 70$, $\beta_R = 0.05$, $V_{BE}(FA) = 0.7$ V, $V_{BE}(SAT) = 0.75$ V, $V_{BC}(RA) = 0.7$ V, and $V_{CE}(SAT) = 0.15$ V. Use $\sigma_O = 0.8$ for the output low state.

a

$$I_{IL} = \frac{V'_{CC} - V'_{BE,I(sat)} - V_{CE,O(sat)}}{R'_B} = \frac{5 - 0.75 - 0.15}{4k} = \frac{4.1}{4k}$$

$I_{IL} = 1.025\,mA$

(b) $I_{OL} = I_{C,O(sat)} = \sigma_{OL} \beta_F I_{B,O(sat)}$

$I_{B,O(sat)} = I_{E,S} - I_{RD}$

$$I_{RD} = \frac{V_{BE,O(sat)}}{R_D} = \frac{0.75}{1K} = 0.75\,mA$$

$$I_{E,S} = I_{C,S} + I_{B,S} = I_{RC} + I_{C,I}(RA)$$

$$I_{RC} = \frac{V_{CC} - V_{CE,S(sat)} - V_{BE,O(sat)}}{R_C} = \frac{5 - 0.15 - 0.75}{1.6K} = 2.56\,mA$$

$$I_{C,I}(RA) = (1+\beta_R) I_{B,I} = (1+\beta_R) I_{RB}$$

$$= (1+0.05) \frac{V_{CC} - V_{BC,I}(RA) - V_{BE,S}(sat) - V_{BE,O}(sat)}{R_B}$$

$$= (1.05) \frac{5 - 0.7 - 2(0.75)}{4K} = 735\,\mu A$$

$$I_{E,S} = 2.56m + 0.735m = 3.295\,mA$$

$$I_{B,O}(sat) = (3.295 - 0.75)m = 2.545$$

$$I_{O,L} = (0.8)(70)(2.545m) = 142.52\,mA$$

(c)

$$N = \frac{I_{OL}}{I_{IL}} = \frac{142.52\,m}{1.025\,m} = 139.04$$

The max fan-out is 139

(d)

$$P_{CC}(avg) = \frac{I_{CC}(OH) + I_{CC}(OL)}{2} V_{CC}$$

$$I_{CC}(OH) = I_{IL} = I'_{RB}(OH) = 1.025\,mA$$

$$I_{CC}(OL) = I_{RB}(OL) + I_{RC}(OL)$$

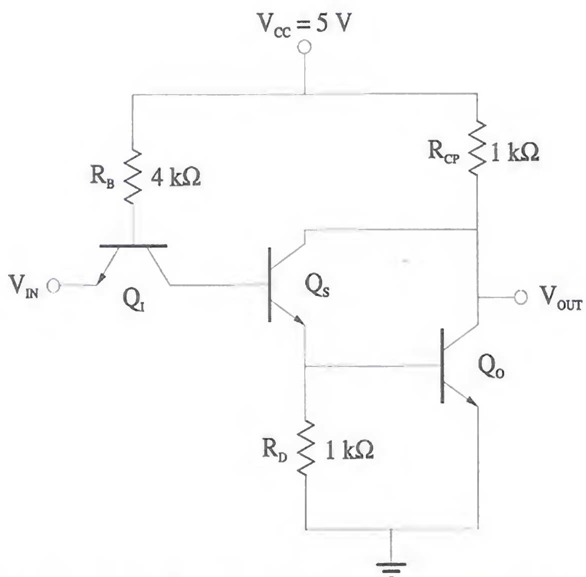
$$= (0.7 + 2.56)m = 3.26\,mA$$

$$P_{CC}(avg) = \frac{1.025m + 3.26m}{2}(5) = 10.71\,mW$$

7.12 For the "special" TTL inverter of Figure P7.12, let $\beta_F = 100$, $V_{BE}(FA) = 0.7$ V, $V_{BE}(SAT) = 0.8$ V, and $V_{CE}(SAT) = 0.1$ V. Obtain the following:

(a) Sketch the VTC.

(b) Determine the average power dissipation.



(a) V_{OH}: * For Vin is low

Q_I is sat, Q_S & Q_o is off

$\boxed{V_{OH} = V_{CC} = 5V}$

V_{OL}: * for Vin is high

Q_I is RA

Assume Q_S is FA & Q_o is off

find $V_{CE,S} = ?$

when Q_o is off

$V_{CE,S} = V_{CC} - I_{Rcp} R_{cp} - I_{E,S} R_D$

$I_{E,S} \simeq \beta_F I_{B,S}$

$I_{B,S} = I_{C,I} = (1+\beta_R) I_{B,I}$

Assume $\beta_R = 0.05$

$V_{CC} - I_{B,I} R_B - V_{BE}(RA) - V_{BE}(FA) - I_{E,S} R_D = 0$

$V_{CC} - I_{B,I} R_B - V_{BC}(RA) - V_{BE}(FA) - \beta_F (1+\beta_R) I_{B,I} R_D = 0$

$$I_{B,I} = \frac{V_{CC} - V_{BC}(RA) - V_{BE}(FA)}{R_B + \beta_F (1+\beta_R) R_D} = \frac{5 - 0.75 - 0.7}{4k + 100(1.05) 1k} = 3.26 \times 10^{-5} \text{ mA}$$

$I_{E,S} = \beta_F (1+\beta_R) I_{B,I} = 100(1.05)(3.26 \times 10^{-5}) = 3.42$ mA

$I_{C,S} \simeq I_{E,S}$

$V_{CE,S} = V_{CC} - I_{C,S} R_{cp} - I_{E,S} R_D = 5 - 2k \times 3.42m = -1.84 V < 0.1$

$\Rightarrow Q_S$ (sat) & Q_o (FA) because BC,o is RB

Q_I (RA), Q_S (sat) & Q_o (FA)

$V_{out} = V_{CE,S}(sat) + V_{BE,o}(FA) = V_{OL}$

$\boxed{V_{OL} = 0.7 + 0.1 = 0.8V}$

V_{IL}: Q_I (sat), Q_S (EOC), Q_o (off)

$V_{IL} = V_{BE,S}(FA) - V_{CE,I}(sat) = 0.7 - 0.1$

$\boxed{V_{IL} = 0.6V}$

V_{IB}: $Q_I(sat),\ Q_S(FA),\ Q_o(EOC)$

$V_{IB} = V_{BE,S}(FA) + V_{BE,o}(EOC) - V_{CE,I}(sat) = 2(0.7) - 0.1$

$\boxed{V_{IB} = 1.3V}$

V_{OB}:

$V_{OB} = V_{CC} - I_{Rcp} R_{cp}$

$I_{Rcp} = I_{C,S} = I_{RD} = \frac{V_{BE,o}(EOC)}{1K} = 0.7mA$

$V_{OB} = 5 - 0.7m \times 1k = 4.3V$

$\boxed{V_{OB} = 4.3V}$

V_{IH}: @ EOS $\Rightarrow Q_I(RA),\ Q_S(sat)\ \&\ Q_o(FA)$

$V_{IH} = V_{BE,S}(sat) + V_{BE,o}(FA) - V_{CE,I}(sat)$

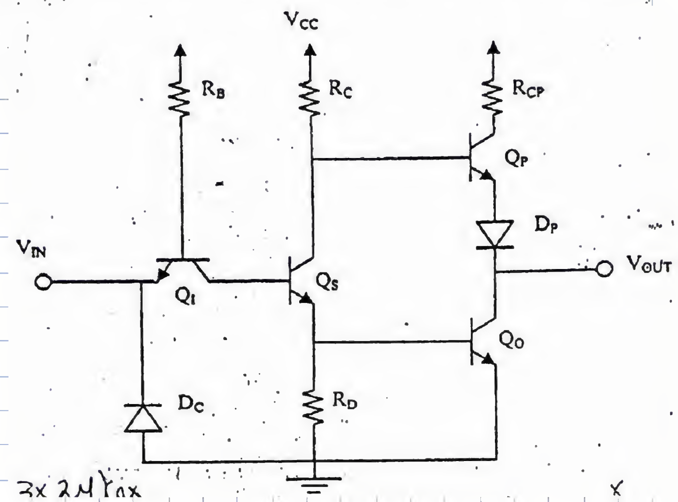
$= 0.8 + 0.7 - 0.1 = 1.4V$

$\boxed{V_{IH} = 1.4V}$

Question 2: [7 Marks]

Consider the following TTL inverter. Assume $V_{BE}(FA) = V_{BC}(RA) = 0.7V$, $V_{BE}(SAT) = 0.8V$, $V_{CE}(SAT) = 0.2V$, $V_D(ON) = 0.7V$, $\beta_F = 90$, $\beta_R = 0.05$, $\sigma_O = 0.8$ for the output low state, $R_B = 40K\Omega$, $R_C = 20K\Omega$, $R_D = 12K\Omega$, $R_{CP} = 500\Omega$, $V_{CC} = 8V$. Do the following:

a) Sketch the VTC.
b) Calculate the maximum fan-out.
c) Calculate the average power dissipation



a

V_{OH}:

For Vin low

Q_I is sat, Q_S & Q_O off

Q_P & D_P at EOC

$V_{OH} = V_{CC} - V_{BE,P}(FA) - V_{D,P}(ON)$

$= 8 - 0.7 - 0.7 = 6.6V$

V_{IL}:

Vin increased until Q_S becomes FA

$V_{IL} = V_{BE}(FA) - V_{CE}(sat) = 0.7 - 0.2 = 0.5V$

V_{IB}:

Vin increases until Q_O becomes FA

$V_{IB} = V_{BE,O}(FA) - V_{BE,S}(FA) - V_{CE,I}(sat)$

$= 2V_{BE}(FA) - V_{CE}(sat) = 2(0.7) - 0.2 = 1.2V$

V_{OB}

As Q_O just turns on

$I_{RC} = I_{RD} = \frac{V_{BE}(FA)}{R_D}$

$V_{OB} = V_{CC} - I_{RC}R_C - V_{BE}(FA) - V_D(ON)$

$= V_{CC} - \frac{V_{BE}(FA)R_C}{R_D} - V_{BE}(FA) - V_D(ON)$

$= 8 - (1 + \frac{20K}{12K})(0.7) - 0.7 = 5.43V$

V_{IH}: Vin increases until Q_O & Q_S becomes saturated

$V_{IH} = V_{BE,O}(sat) + V_{BE,S}(sat) - V_{CE,I}(sat)$

$= 2V_{BE}(sat) - V_{CE}(sat) = 2(0.8) - 0.2$

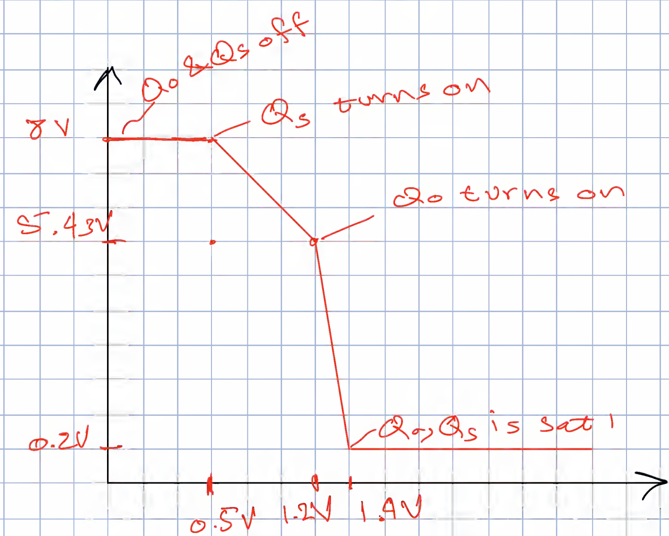
$V_{IH} = 1.4V$

V_{OL}

Q_O in saturation

$V_{OL} = V_{CE}(sat) = 0.2V$

Q_P is therefore cutoff



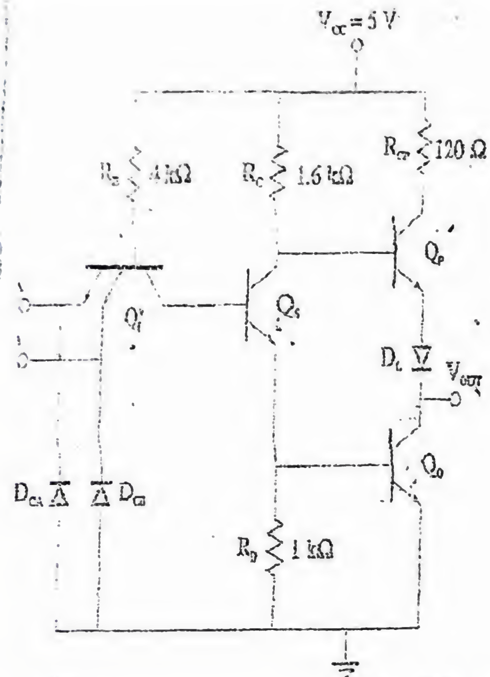
Element	V_{OH}	V_{OB}	V_{OL}
Q_I	sat	sat	RA
Q_S	cutoff	FA	sat
Q_P	EOC	FA	cutoff
D_P	EOC	EOC	cutoff
Q_O	cutoff	EOC	sat

Explain the operation of the totem-pole output buffer.

* R_{cp} & Q_p provides active pull-up. thus a large current is available for charging the equivalent load capacitance when the output switches from low to high

Q_O	Output inverting BJT, output low driver for current sourcing pull-down
D_L	Diode level shifting between V_{CC} and output

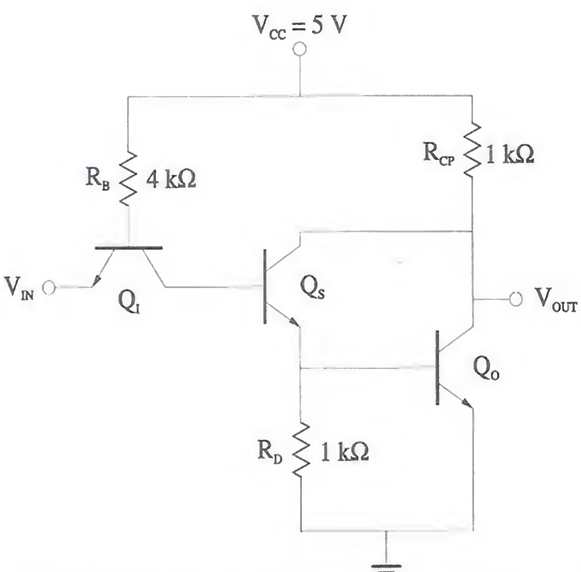
* Q_p & Q_o are never on simultaneously



7.12 For the "special" TTL inverter of Figure P7.12, let $\beta_F = 100$, $V_{BE}(FA) = 0.7$ V, $V_{BE}(SAT) = 0.8$ V, and $V_{CE}(SAT) = 0.1$ V. Obtain the following:

(a) Sketch the VTC.

(b) Determine the average power dissipation.



V_{OH}:

For V_{IN} is low

Q_s & Q_o is off

$\boxed{V_{OH} = V_{CC} = 5V}$

V_{IL}:

As V_{IN} increases Q_s enters EOC at

$V_{IN} = V_{BE,S}(FA) - V_{CE,I}(sat) = V_{IL}$

$= 0.7 - 0.1 = 0.6V$

$\boxed{V_{IL} = 0.6V}$

V_{IB}:

As V_{IN} increases further $Q_s(FA)$ & Q_o enters EOC

$V_{IB} = V_{BE,o}(FA) + V_{BE,S}(FA) - V_{CE,I}(sat)$

$\boxed{V_{IB} = 2(0.7) - 0.1 = 1.3V}$

V_{OB}:

As Q_o just turns on

$V_{OB} = V_{CC} - I_{RCP} R_{CP}$

$I_{RCP} \approx I_{C,S} \approx I_{RD} = \frac{V_{BE}(FA)}{R_D} = \frac{0.7}{1k} = 0.7mA$

$V_{OB} = 5 - 0.7m \times 1k = 5 - 0.7$

$\boxed{V_{OB} = 4.3V}$

V_{IH}:

As V_{in} increases further Q_s just enter saturation

$V_{IH} = V_{BE,S}(sat) + V_{BE,o}(FA) - V_{CE,I}(sat)$

$= 0.8 + 0.7 - 0.1 =$

$\boxed{V_{IH} = 1.4V}$

V_{OL}:

Q_I enters RA & Q_s (sat) & Q_o (FA)

$V_{OL} = V_{CE,S}(sat) + V_{BE,o}(sat) = 0.1 + 0.7$

$\boxed{V_{OL} = 0.8V}$